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Achieving 1% Tandem Polymer Solar Cells

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Final Report

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Final Progress Report

Grant Award Number: FA 9550-12-1-0074
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(03/15/2013-03/14/2015)

Title: Achieving 15% tandem polymer solar cells

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University of California – Los Angeles, CA

Abstract

We would like to thank AFOSR for the support of this project. This is a highly productive research project (27 papers in three years, on journals of Science, Nature Photonics, Nature Communications, Advanced Materials, JACS, Advanced Functional Materials, Advanced Energy Materials, Nano Letters, ACS Nano, Angewandte Chemie International Edition, etc. aiming to (1) develop novel low bandgap conjugated polymers for high efficiency tandem solar cell – single junction cell with 9% PCE achieved (2) develop tandem solar cell structures – both polymer only and hybrid tandem cells to constantly pushing the envelope of solution processed solar cell performance – 11.6% polymer tandem cell, 7% transparent tandem polymer cell, and over 10% PCE hybrid tandem solar cells were achieved. In addition, AFOSR's final support also enabled us to explore novel hybrid perovskite solar cells in depth. For example, single junction cell efficiency of 19.3% under reverse bias was achieved and the results was published on Science.

Final Report

In the first year into the project, we demonstrated tandem polymer solar cells with 10.6% power conversion efficiency, certificated by NREL. We have also developed new low bandgap polymer (PBDTT-SeDPP) for our tandem solar cells. In addition, we have designed novel all inorganic interconnecting layer (TiO_2/ITO NPs/V_2O_5) for stable solar cells. Six papers [1-6] were published on the journals of Nature Photonics, Nature Communications etc.

The achievements in Year 2 and 3 are describes below.

I. New polymer development, morphology and novel tandem structure for polymer solar cells

1. New polymer development [Ref. 7, 8]

Using a triple component random copolymerization approach, the amount of triethylene glycol (TEG) side chain, which can be regarded as a stack-inducing agent, is introduced precisely into a given polymer backbone. TEG side chains result in a more favorable morphology in a polymer:fullerene blend. Based on the low-bandgap photovoltaic polymer with alternating thienylbenzodithiophene (BDTT) and DPP units - PBDTT-DPP (PBD), this methodology can bring a 10% overall improvement in power conversion efficiency (PCE).[7]

Based on the long standing champion polymer based on thienotheophene and benzodithiophene, as well as our successful experience of selenophene in PBDTT-DPP polymer, we developed a selenophene-modified PTB7, PBDTSe-TT. The structure adjustment carried out by alkylselenophene substitution on the BDT building block is shown to slightly affect the polymer's electronic property, and very importantly, an enlarged VOC of the resulting photovoltaic device is observed. More importantly, the PBDTSe-TT:PC71BM bulk-heterojunction thin film morphology can be optimized through this modification. As a result, an efficient PCE of 8.8% is achieved without using any solvent additive or special interfacial layer. In addition, the PBDTSe-TT-based device is relatively stable under thermal stress, making it a good candidate for fabricating tandem cells. A 10% PCE HOMO tandem device is demonstrated by using identical PBDTSe-TT:PC71BM subcells. [8]

2. Morphology understanding [9]

We observed the power conversion efficiency (PCE) of a DPP-based polymer solar cell is significantly improved by using DIO or DCB as processing additives. Interestingly, we found that DCB outperforms DIO with a significantly wider solvent mixture operation window, which suggests different optimization mechanisms. With the assistance of advanced characterization tool such as Grazing Incident X-Ray Diffraction (GIXRD), and Small angle Neutron scattering (SANS), we provided a more detailed understanding of morphology in these polymers. Although both solvent mixture systems involve double aggregation processes, including a similar solution-to-film aggregation, however, two distinct solution-stage aggregations are observed: relatively amorphous polymer aggregates form in the CF-DIO solution, while more crystalline polymer aggregates form in CF-DCB solution.

3. Novel tandem polymer solar cells

We first demonstrated HOMO Polymer tandem solar cells with 10.2% power conversion efficiency via stacking two PDTP-DFBT:PC71BM bulk heterojunctions, connected by MoO3/PEDOT:PSS/ZnO as an interconnecting layer. The tandem solar cells increase the power conversion efficiency of the PDTP-DFBT:PC71BM system from 8.1% to 10.2%, successfully demonstrating polymer tandem solar cells with identical sub-cells of double-digit efficiency. [10]

The envelop of tandem polymer solar cell was further push forward by successfully realizing triple junction structure using three polymers with bandgap of 1.9eV (P3HT), 1.58eV (PTB-Th) and 1.38 eV (PDTP-DFBT). Optical simulation was successfully applied to guide the multiplayer tandem cell design. The 11.6% triple junction tandem polymer solar cell achieved is only possible with the earlier efforts on novel polymer, interconnection layer, and device structure innovation. [11]

We also successfully demonstrated tandem transparent polymer solar cells by incorporating Ag NW based composite transparent electrode. In this work, we tuned the absorption and light conversion properties of polymer solar cells from visibly transparent to semi-transparent via active layer engineering, making them more versatile for integrated photovoltaic applications and more efficient under solar illumination. Our best transparent solar cell was a tandem PSC exhibiting an efficiency of 6.4% and a maximum transmission of 51% at 550 nm. Semi-transparent tandem PSC having an average transmission of 30% in the visible range exhibited power conversion efficiency greater than 7% was also achieved. [12]

II. Hybrid tandem solar cells

Polymer solar cell is successfully integrated first with amorphous silicon solar cell to form hybrid tandem solar cells in this project, where a-Si:H film was as a front sub-cell and a low band gap (LBG) polymer:fullerene blend film as a back cell on planar glass substrates. Monolithic integration of 6.0% efficiency a-Si:H and 7.5% efficiency LBG polymer:fullerene blend solar cells results in a power conversion efficiency of 10.5%. To our knowledge, this is the first time a-Si/OPV tandem cell achieves over 10% efficiency. Such high-efficiency thin-film tandem cells was achieved by optical management and interface engineering of fully optimized high performance front and back cells without sacrificing photovoltaic performance in both cells. [13]

In a second effort, a monolithic integration of perovskite and LBG polymer:fullerene subcells into a tandem structure is realized through a full solution process. The wide bandgap perovskite absorber (CH3NH3PbI3) is processed via a one-step deposition employing an additive-assisted solvent wash method. In particular, a small molecule additive, BmPyPhB, is added into the precursor solution to improve the uniformity of the initial nucleation process of the crystal by providing heterogeneous nucleation sites throughout the solution. The all solution process hybrid tandem solar achieved 10.2% power conversion efficiency. [14]

III. Organometal halide hybrid pervskite (PVSK) solar cells

In the past 5 years, solar cells based on organometal halide hybrid pervskite materials attract tremendous attention due to their solution processibility, high mobility, excellent absorption coefficient, low cost etc. The efficiency progress is amazing – from less than 4% in 2009 to currently over 20%, which is the fastest progress in the history of solar cells. Taking advantage of the AFOSR grant, our group has played significant role in the progress of perovskite solar cells. Under the support of AFOSR, we have published 10 papers [15–24] on high impact journals on this topic in the past two years. The works covers wide range of the research topics in the field, and some of the highlights are the following:

1. New process – we developed a novel vapor-assisted solution (VASP) process for perovskite film growth. This technique significantly improved the uniformity and smoothness of the PVSK film, which will be critical for the manufacturability of this solar cell technology. [15]
2. Instead of the traditional sintered (>400^{o}C process) TiO_2 based perovskite solar cell, we successfully achieved low temperature (<120^{o}C) process but high performance flexible pervskite solar cell with 9.2% efficiency. [16]
3. Opposite to conventional thoughts, we recently identified moisture can assist to significantly improve the PVSK film's formation. Very high fill factor of over 80% can be achieved. [17]
4. By controlling the formation of the perovskite layer and interface engineering, we suppressed carrier recombination in the perovskite absorber, facilitated carrier injection into the carrier transport layers, and maintained good carrier extraction at the electrodes.

Solar cell PCE is typically boosted to 16.6% on average via reverse bias scan, with the highest efficiency of ~19.3% in a planar geometry. The whole fabrication process was conducted in air and from solution at low temperatures, which is a big plus for manufacturing of large-area perovskite devices that are inexpensive and perform at high levels. The work was published in the journal of Science. [18]

IV. Review articles

We also contributed two review articles on prestigious journals – an Advanced Materials 25-Year anniversary review of polymer solar cell, and one on Progress of Polymer Science on tandem polymer solar cells.

In summary, the project in the past three years is very fruitful. We pushed the OPV efficiency to 11.6%, which came from our systematic efforts of interface engineering, tandem device structure and material innovation. We also demonstrated hybrid tandem solar cells using a-Si + OPV, and peroskite + OPV structures, and in both cases achieved over 10% PCE. Exciting progress on perovskite solar cells have been achieved in UCLA under the support from AFOSR, which paves the way for future academic and commercialization breakthroughs.

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Bandgap Polymers Designed for Single Junction and Tandem Polymer Solar Cells. Journal of American Chemical Society, 134, 10071 (2012)

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7. Wei-Hsuan Chang, Lei Meng, Letian Dou, Jingbi You, Chun-Chao Chen, Yang (Michael) Yang, Eric Patrick Young, Gang Li and Yang Yang. A Selenophene Containing Benzodithiophene-alt-thienothiophene Polymer for Additive-Free High Performance Solar Cell. Macromolecules, Article ASAP (2015)

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Hybrid tandem solar cells

13. Jeehwan Kim, Ziruo Hong, Gang Li, Tze-bin Song, Jay Chey, Yun Seog Lee, Jingbi You, Chun-Chao Chen, Devendra K. Sadana and Yang Yang. 10.5% efficient polymer and amorphous silicon hybrid tandem photovoltaic cell. Nature Communications 6 (2015)

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Organometal halide perovskite solar cells

15. Qi Chen, Huanping Zhou, Ziruo Hong, Song Luo, Hsin-Sheng Duan, Hsin-Hua Wang, Yongsheng Liu, Gang Li, and Yang Yang. Planar Heterojunction Perovskite Solar Cells via Vapor-Assisted Solution Process. Journal of American Chemical Society, 136 (2), 622–625 (2014)

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26. Letian Dou, Jingbi You, Ziruo Hong, Zheng Xu, Gang Li, Robert A. Street, Yang Yang. 25th Anniversary Article: A Decade of Organic/Polymeric Photovoltaic Research Advanced Materials, published online (2013)

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Yang Yang

Program Manager

The AFOSR Program Manager currently assigned to the award

Charles Lee

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Archival Publications (published) during reporting period:

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Changes in research objectives (if any):

Change in AFOSR Program Manager, if any:

Extensions granted or milestones slipped, if any:

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

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